Case Studies in Engineering Failure Analysis 2 (2014) 61–68

Contents lists available at ScienceDirect

Case Studies in Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/csefa

Case study

An investigation into failure analysis of interfering part of a steam turbine journal bearing

M. Mehdizadeh [a,*], F. Khodabakhshi [b]

[a] Metallurgy Department, Niroo Research Institute (NRI), Tehran, Iran
[b] Department of Materials Science and Engineering, Sharif University of Technology, P.O. Box 11365-9466, Azadi Avenue, 14588 Tehran, Iran

ARTICLE INFO

Article history:
Received 17 December 2013
Received in revised form 5 April 2014
Accepted 8 April 2014
Available online 6 May 2014

Keywords:
Failure analysis
Steam turbine
Journal bearing
Fretting fatigue

ABSTRACT

Journal bearings as so sensitive parts of steam turbines are very susceptible to failure through different mechanisms of wear, fatigue and crush during service conditions. Failure occurring through these mechanisms lead to turbine completely shut down as a result of interfering in working conditions of bearing different parts. In this research, failed interfered part of a journal bearing related to a 320,000 kW steam turbine was examined. Failure analysis investigations were performed by utilizing of stereographic, optical microscopy, scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS) analysis and hardness test. Surface crush, large amounts of surface cracks, no noticeable changes of failed surface chemical composition and microstructure with significant hardness improvement were the main obtained results. The studies were revealed that the bearing part loosing and inappropriate clearance can produce relative displacements under cyclic gradient loading. This condition was detrimental for the service life of turbine journal bearing via failure through fretting fatigue mechanism.

1. Introduction and background

Damaging through bearings as the main backing for the rotating parts may lead to interfering of the fixed and rotating tools with some changes in their positions. This can be a source for bearing axis bending and subsequently may lead to its fracture. In the other cases, the temperature of other parts increased as a result of mentioned damaging. When a bearing is damaged, it is often removed from service and replaced before reaches to its full, useful and economical life. Advancements in bearing design, materials, bearing maintenance and repair methods have greatly improved the potential for and popularity of the bearing repair as an effective way to extend the life of the bearing [1].

Two different types of bearing are utilized in the construction of steam turbines including; journal and thrust. The first type preventing from vertical movement of bearing axis and the second thrust one fixed the axis through longitudinal direction [2,3]. Turbine bearing failures in electric utilities have been responsible for outages amounting to ~1.1–1.8% of the theoretical power output. Significant imposed additional costs due to bearings damaging and consequent unexpected unit shut down leads to performing of widespread failures analysis studies in order to drawing of a beneficial procedure for overcoming from this problem. It has been reported sixteen damaging mechanisms for failure of steam turbine journal

* Corresponding author. Tel.: +98 21 88078296; fax: +98 21 88079400.
E-mail address: mmehdizadeh@nri.ac.ir (M. Mehdizadeh).

http://dx.doi.org/10.1016/j.csefa.2014.04.001
2213-2902/

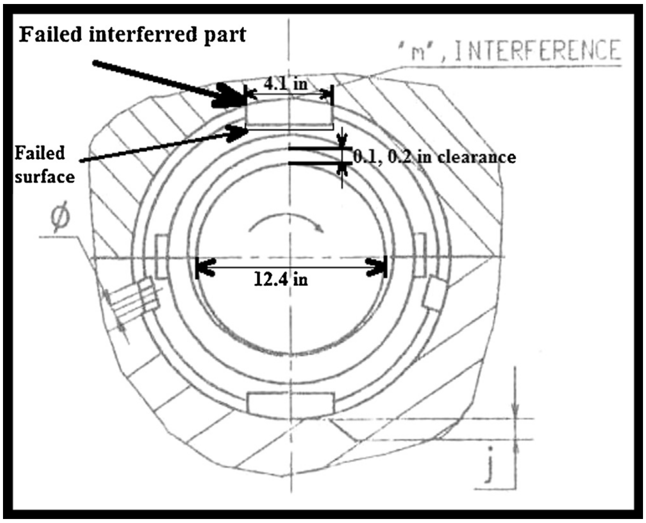

Fig. 1. Schematics represent the journal bearing assembly.

bearings as well as; abrasion, bond failure, cavitations erosion, corrosion, electrical pitting, erosion, fatigue, fretting, high chromium damage, non-homogeneity, overheating, seizure, structural damage, surface wear, tin oxide damage and wiping [2]. Some of these damaging mechanisms more frequently contributed through bearing failure which short expressions about them summarized as follow.

Abrasion is a mode of bearing failure due to the erosive action of a large number of solid particles that are harder than the bearing surface. Under certain conditions both the bearing and shaft may be damaged by the abrasive action of the particles [2]. Fatigue and bond failure are two other main damage mechanisms for bearings failure. Bond failure is a separation of the bearing alloy from the supporting structure at the interface between the two metals, and is caused by poor adhesion of bearing alloy to the backing metal [2]. Fatigue failure is the cracking and fracture of metals due to an excessive number of cycling stresses when the stress level is above a threshold limit characteristic for a specific material at a specific temperature [2]. Despite no applied cyclic loading through bearing service condition, fatigue failure performed due to un-equilibrium loading condition and Babbitt low strength. Fretting is another form of corrosion or fatigue surface damages occurs on contacting components subjected to small amplitude oscillatory motions which can leads to bearing failure [2]. If fretting assisted by oxidation of worn steel with leaving of corroded appearance, it's often referred to as fretting corrosion [3]. Shrunk-on parts, bearing pivots, loose bearing shells and similar parts prone to repeated relative movements are most susceptible to this sort of damage. When fretting phenomenon arises from cyclic stressing of one or both components, it's often known as fretting fatigue [3]. In this case, according to the contact geometry and the in-service loading conditions, fretting fatigue can result either in material system locking or material wear and mechanical systems looseness or early fatigue crack nucleation and propagation until failure, reducing drastically the service life of the components [4,5]. Several factors affected the fretting fatigue behavior of materials, in which contact pressure, coefficient of friction, slip amplitude, and cyclic axial stress are relatively important [6–8].

In the steam turbines, usually journal bearings which constructed from several parts have been utilized. The backing parts are made generally from hard steels provides rigidity and allows higher levels of press fit or crush for better retention [9]. Inter contacting with lining parts and in-service complex loading conditions leads to more susceptibility of journal bearings to some of the mentioned failure mechanisms such as; abrasion, fatigue, fretting and may bond failure. In the present research, failure analysis of a failed interfering journal bearing part of a steam power plant turbine was assessed and failure mechanism determined by monitoring of the metallurgical characteristics and failure features through different microstructural and mechanical experiments.

2. Materials and methods

During repairing of a 320,000 kW steam turbine, after disassembling of bearing journal-pad type, some surface damages on its interfering part have been observed. Fig. 1 illustrates the general location view of this damaged part in journal bearing

Table 1
Nominal chemical composition of investigated Q235B steel (in wt.%).

Fe	C	Si	Mn	Cr	Ni	Cu
Base	0.12–0.2	0.3	0.3–0.7	0.3	0.3	0.3

assembly. Damaged part was located on the half top side. Examination of recorded data histories revealed that six month after previous repairing operation rotor vibration was increased significantly. Turbine vibrations almost were started at loads higher than 280,000 kW, while oil quality not varied during operation. This specimen made from Q235 steel according to Chinese standard with chemical composition presented in Table 1. It seems that nominal composition is so near to low carbon steel. In order to study the failure mechanism of investigated part, following procedure was employed. With using electronic macro imaging and stereographic microscopy, failed surface features were studied. For microstructural

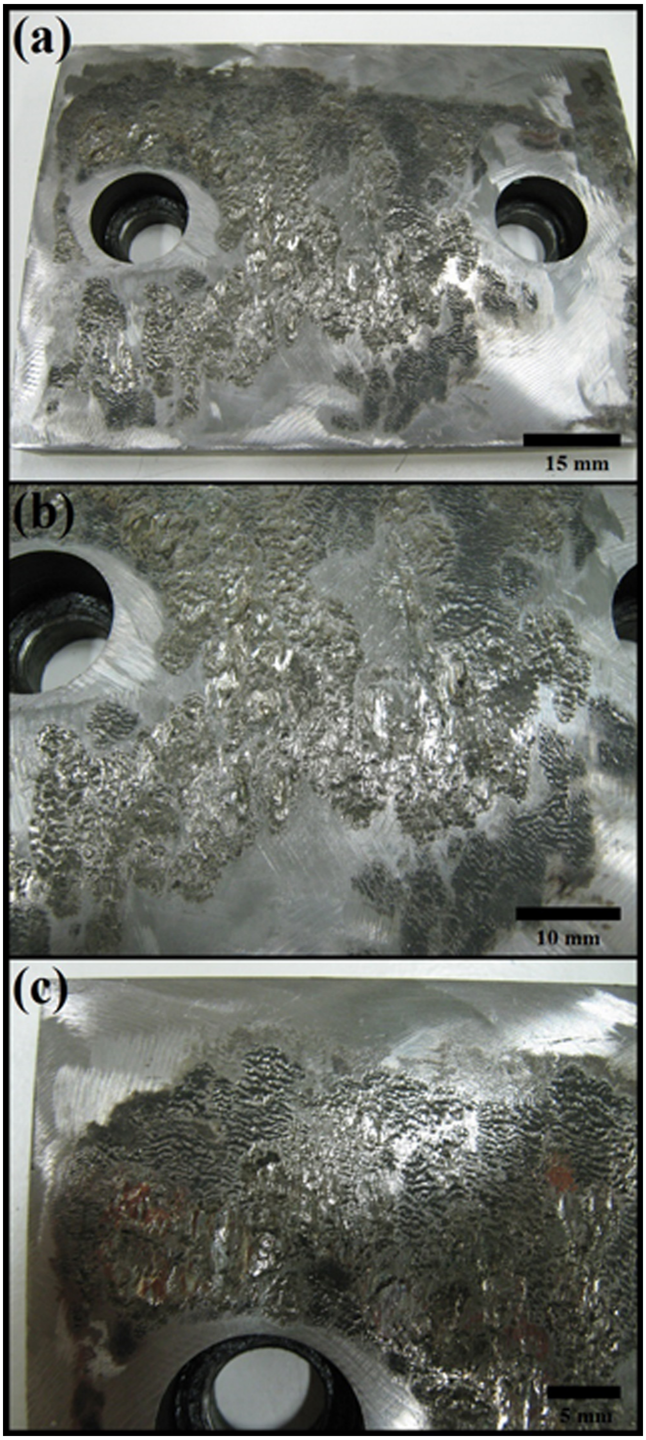

Fig. 2. Macro images of failed interfering part of turbine journal bearing.

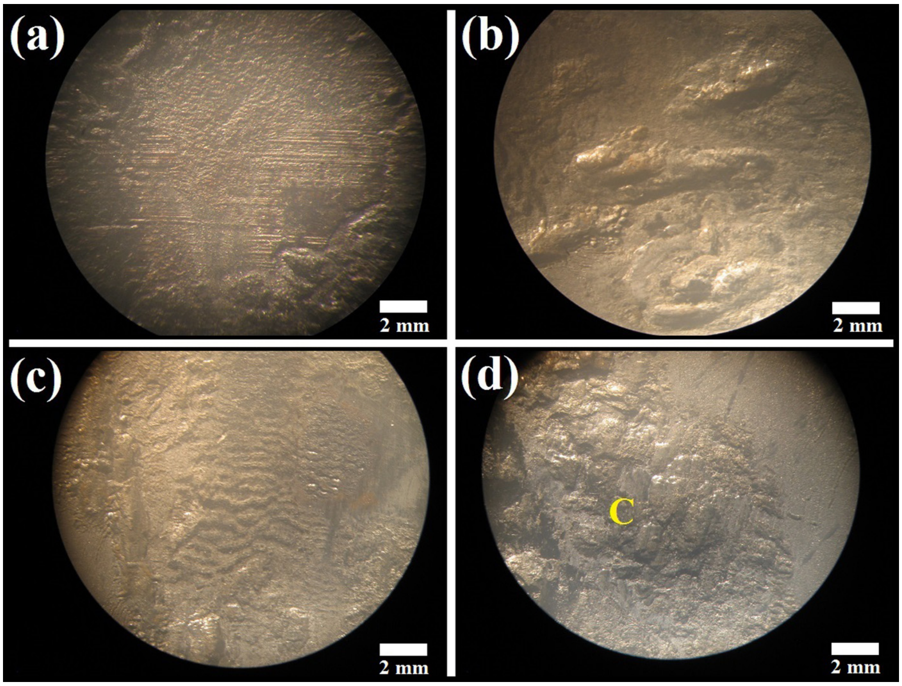

Fig. 3. Stereographic macro images of failed sample surface.

examinations of deformed surface layer, small samples were cut from thickness cross section and thereafter standard metallographic procedure employed. Samples were etched via a chemical solution containing 96% CH_3OH and 4% HNO_3 before optical microscopy and observations performed with utilizing an Olympus PME3 microscope equipped with a CLEMEX-BX51M digital camera. The more microstructural details about the failed surface were examined through scanning electron microscopy (SEM, JEOL, Japan) from the metallographic cross section. With using energy-dispersive X-ray spectroscopy (EDS), chemical analysis was carried out from some selected locations in the surface and thickness cross sections of the failed samples. Vickers hardness characteristics of mentioned steel part before and after failure were evaluated by Bohler instruments (Bohler, Germany) with an applied load of 30 kg at 20 s dwell time.

3. Results

3.1. Fractographic analysis

Low magnified electronic macro images represent the failed surface of interfering part of journal bearing is demonstrated in Fig. 2. The overall view of surface area revealed that it was totally subjected to a phenomenon such as cyclic crushing with relatively deep holes in some regions. Surface of this dished area seems approximately shiny near to polish. Also, surface partially covered by some brown substances which were the result of low carbon steel oxidation or oily inclusions. Also, the close view showed that there are some deformation paths and crushed zones at this area. The magnified appearance of this deformed surface is shown in Fig. 3. These stereographic micro images illustrate some small regular features related to wear paths.

3.2. Metallurgical examination

Fig. 4 shows the optical microstructures of damaged surface from the thickness cross section. As can be seen, initial base steel has a ferritic microstructure with approximately 25 vol.% pearlite content. In the surface layer, fretting via intense deformation, cracking and crush can be observed. In addition, micrographs represent a lot of small micro cracks at the interface of deformed surface layer with the substrate steel. As the same as, in SEM images of Fig. 5 large amounts of surface cracks, severely deformation of metal surface and fretting of surface layer were found. The EDS analysis was carried out from points of A and B in thickness cross section (shown in Fig. 5) and point of C in the sample surface (shown in Fig. 3). The EDS spectra are shown in Fig. 6 and the obtained elemental results reported through Table 2 These three points of A to C are displayed the chemical analysis related to foreign contaminations, metal oxide surface layer and base steel, respectively. Surface chemical composition determined by EDS analysis has been modified due to surface oxidation and mechanical mixing (oils with metal fines and oxides) promoted by fretting fatigue process. Subsurface microstructure exhibited

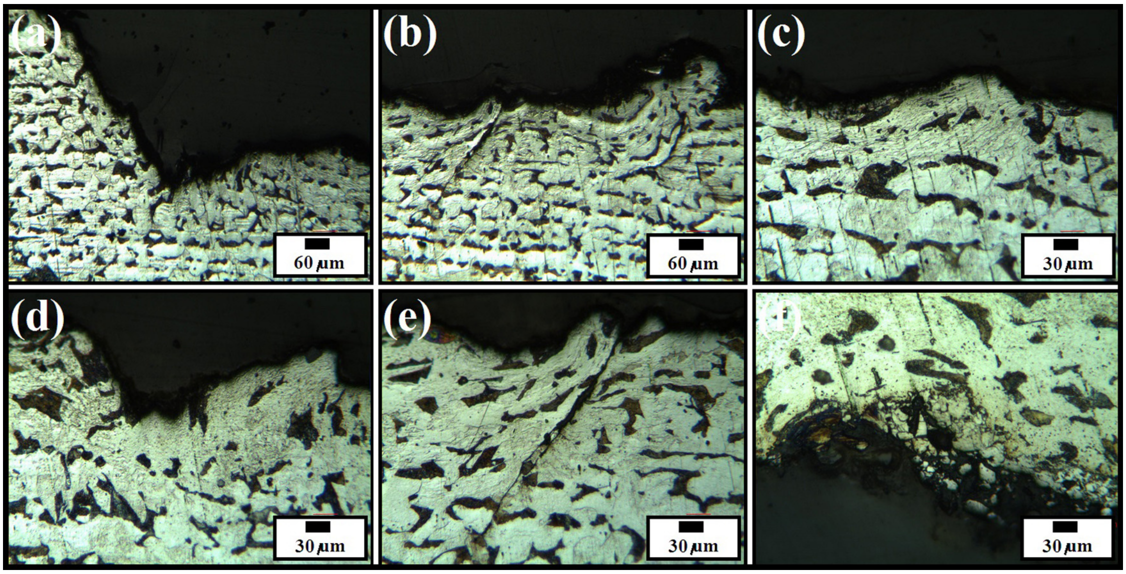

Fig. 4. Optical microstructures related to damaged surface layer from thickness cross section.

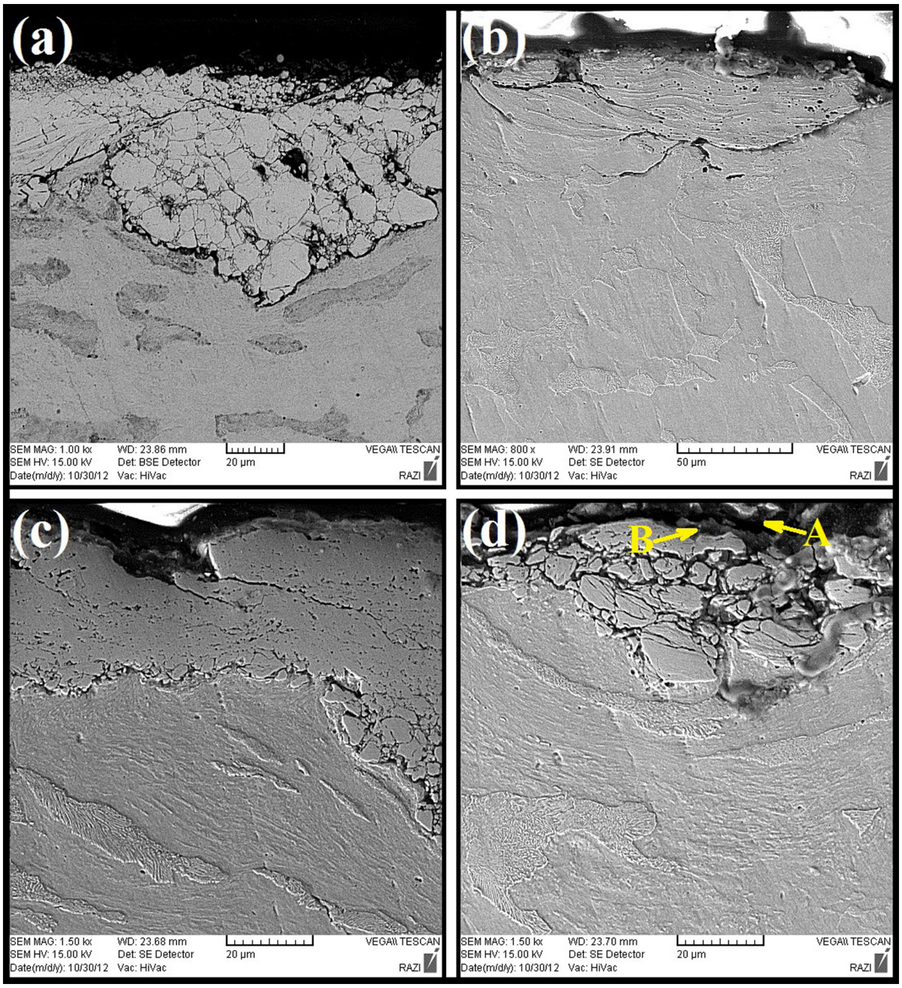

Fig. 5. The SEM microstructures of failed sample cross section.

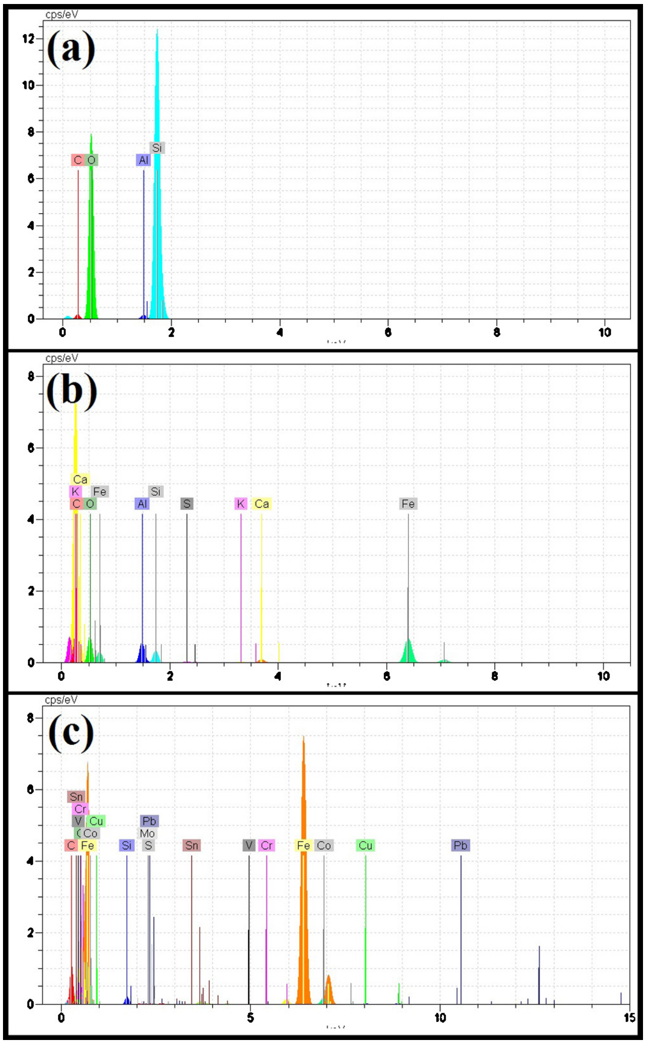

Fig. 6. The EDS analysis spectra correspond to (a) A, (b) B and (c) C scan points, respectively.

significant plastic deformation due to cold working (even though there was no evidence of subsequent deterioration induced by thermally affected phase transformation or decarburization).

3.3. Hardness measurement

In order to investigate the mechanical properties evolutions after failure, Vickers macro-hardness measurements were carried out along different paths through thickness cross section. For sample core (out of damaged zone), mean hardness was measured ~132 Vickers which is also in consistence with hardness of un-serviced Q235 steel. But, hardness values related to failed area were so varied depends on the amount of fretting and crush imparted damages. However, a mean hardness ~350 Vickers was determined for the damaged surface layer. Considerable increasing of surface hardness (about three times higher) is due to significant dislocation density increscent as a result of intensive cold working process during failure.

4. Discussion

The failure mechanism of discussed sample which was related to an interfering part of steam turbine journal bearing determined as fretting fatigue with considering the conditions of fretting wear and some visible features of fretting pits and cracks on the surface without any changes through microstructure and chemical composition. But, the main question is why did the fretting fatigue happen at the contact region between this backing support and rigid bearing inner part? And how it would be possible to diminish this problem? Fretting damage has a cyclic nature similar to fatigue rupture. Occurrence of micro-slips between the contacting surfaces without rotation can be considered as the main differences of fretting fatigue

Table 2
Chemical composition of points (a) A, (b) B and (c) C, obtained from EDS analysis. High carbon contents in these analysis results are corresponding to contaminations or journal bearing oil.

Element	Series	unn. C (wt.%)[a]	Norm. C (wt.%)	Atom. C (at.%)
(a)				
Carbon	K series	2.38	2.13	3.35
Oxygen	K series	67.60	60.53	71.50
Aluminum	K series	0.53	0.47	0.33
Silicon	K series	41.18	36.87	24.81
(b)				
Carbon	K series	22.27	30.03	49.06
Oxygen	K series	20.64	27.84	34.15
Aluminum	K series	2.29	3.09	2.25
Silicon	K series	1.28	1.72	1.21
Sulfur	K series	0.16	0.22	0.13
Potassium	K series	0.16	0.22	0.11
Calcium	K series	0.68	0.92	0.45
Iron	K series	26.66	35.95	12.63
(c)				
Carbon	K series	3.59	3.41	13.91
Oxygen	K series	0.71	0.68	2.08
Silicon	K series	0.43	0.41	0.71
Sulfur	K series	0.00	0.00	0.00
Vanadium	K series	0.03	0.03	0.03
Chromium	K series	0.64	0.61	0.57
Iron	K series	95.20	90.41	79.39
Cobalt	K series	2.67	2.54	2.11
Copper	K series	1.20	1.14	0.88
Molybdenum	K series	0.18	0.18	0.09
Tin	K series	0.52	0.49	0.20
Lead	K series	0.12	0.11	0.03

[a] unn., un-normalized.

and pure fatigue. Herein, fix inter-contacted specimens such as bearing's shell outside parts, interfered connections and similar contacting surfaces are so sensitive to fretting fatigue phenomenon. Relative to plain fatigue, fretting fatigue displays a number of important features which must be considered in any analysis of experimental results or design situations [5], includes; stress gradients are likely to be very high due to the localized stress concentration at the contact, loading is likely to be non-proportional in the neighborhood of the contact caused by the non-linear nature of the friction at the contact interface, initiated cracks will experience a variable *R*-ratio as they grow away from the contact and localized surface damage at the asperity level may play a role in accelerating the initiation of cracks at the asperity scale. For the examined interfering part, some designing inaccuracies such as loosing of bearing backing part or inner part and insufficient fastening of journal bearing set can produce small relative slips or displacements between contacting metal surfaces and subsequently under complicated service loadings leads to occurring of fretting fatigue failure. Meanwhile, for reducing from the susceptibility to fretting phenomenon following corrections can be considered; improvement of bearing part steel quality, accurate clearances for the bearing parts exactly according to designer suggestions and increasing of bearing shell thickness. Furthermore, it is recommended to disassemble the journal bearing at regular time intervals, in this case for example five months, for controlling the clearance of different parts. It should be noted that if occurring of fretting fatigue for inner bearing parts leads to rotor vibration, superimposing of fretting and rotor effects enhance the damaging intensity, continuously.

5. Conclusions

Failure analysis investigations were carried out on a failed interfering part of journal bearing related to turbine of a steam power plant. In order to indicating the failure mechanism, visual and experimental investigations were performed. Vickers hardness of cold worked surface was increased about three times with respect to initial base steel. Chemical composition and microstructure of the failed zone were so closed to initial base metal. Moreover, large amounts of cracks and localized ups-downs deformation paths on the surfaces were observed. Fretting wear and subsequent fatigue were the damage processes caused by micro slip under high cycle fatigue loading between interfering bearing part and contacting structural members. The service life of journal bearings can be improved by using appropriate assembly with accurate clearance.

References

[1] Alexander J. Bearing repair provides valuable alternative to bearing replacement for heavy industries. South Carolina: Timken Industrial Service Center; 1985.

[2] Pinks O. Manual of bearing failures and repair in power plant rotating equipment, EPRI GS-7352; 1991.
[3] Welsh RJ. Plain bearing design handbook. London/Boston: Butterworth's; 1983.
[4] Wei DS, Wang YR, Yang XG. Eng Fail Anal 2011;18:314–24.
[5] Wei DS, Yuan SH, Wang YR. Eng Fail Anal 2012;26:381–96.
[6] Petiot C, Vincent L, Dang Van K, Maouche N, Foulquier J, Journet B. Wear 1995;181–183(Part 1):101–11.
[7] Tang H, Cao D, Yao H, Xie M, Duan R. Eng Fail Anal 2009;16:2004–8.
[8] Lee YH, Kim JY, Kim HK. Eng Fail Anal 2009;16:1238–44.
[9] Sudhakar KV, Cruz Paredes J. Eng Fail Anal 2005;12:35–42.